(1722 JS)

Patent
Case No.: 55955US002

RECEIVED
JAN 0 2 2003
TC 1700

OIPE JC130
DEC 2 6 2002
PATENT & TRADEMARK OFFICE

32692
PATENT TRADEMARK OFFICE

RECEIVED
SEP 1 1 2003
TC 1700

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	DAVIS, SARAH J.		
Application No.:	09/966946	Group Art Unit:	1722
Filed:	September 27, 2001	Examiner:	Unknown
Title:	CERAMIC OXIDE PRE-FORMS, METAL MATRIX COMPOSITES, AND METHODS FOR MAKING THE SAME		

SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT

Commissioner for Patents
Washington, DC 20231

CERTIFICATE OF MAILING
I hereby certify that this correspondence is being deposited with the United States Postal Service as First Class Mail in an envelope addressed to: Commissioner for Patents, Washington, DC 20231 on:

December 18, 2002 — Lisa Hengen
Date — Signed by: Lisa Hengen

Dear Sir:

Pursuant to 37 C.F.R. §§ 1.56 and 1.97-1.98, based on information provided by one of the Applicants, the following is a brief description of events relevant to this application which took place prior to the filing of Provisional Application No. 60/236,092, filed September 28, 2000:

More than one year prior to September 28, 1999, the assignee of the present application sponsored a survey conducted by market study firms, such as SRI International, to explore various markets for utilization of 3M's ceramic oxide fibers, particularly its NEXTEL™ 610 Ceramic Oxide Fiber. A reducted version (excluding pages 5-14, certain numbered pages following page 21 and to remove specific information which identifies third parties) of SRI International's report is attached and is identified as Exhibit A. The use in brake calipers is one of the applications mentioned in the report.

12/31/2002 BABRAHA1 00000008 133723 09966946
01 FC:1806 180.00 CH

RECEIVED
FEB 0 9 2004
TC 1700

RECEIVED
JAN 1 6 2003
GROUP 3600

Applicants admit that in May 1999, a first third party contacted 3M regarding metal matrix composite properties posted on 3M's Metal Matrix Composite website. 3M no longer has a copy of the text of what was posted on the website in May of 1999. The current posting on the website is included herewith as Exhibit B which describes the physical properties of the Nextel™ Ceramic Fibers and their use in reinforcement of aluminum in the same detail as was described in May of 1999 although the website now provides additional description of using the ceramic fibers, for example, to reinforce brake calipers. The first third party expressed a particular interest in the high specific stiffness and low density of 3M's metal matrix composite materials. The first third party said they were interested in using the material in brake calipers for motor vehicles.

Prior to September 28, 1999 3M agreed to attempt to design an aluminum version of one of the first third party's brake calipers selectively reinforced with Nextel™ 610 Ceramic Oxide Fibers. To assist in such a design, a second third party provided 3M with CAD (Computer Aided Design) files of the cast iron version of the brake caliper. The first third party indicated that they required the aluminum version of the brake caliper needed to match (i.e., not exceed) the deflection of the cast iron version while maintaining the same packaging envelope.

On September 28, 1999, the first third party, and the second third party, met with 3M to view presentations by 3M regarding the reinforcement of aluminum brake calipers for motor vehicles using Nextel™ 610 Ceramic Oxide Fibers (see Exhibit C which has been redacted to remove specific information which identifies third parties). The 3M presentations included the use of a mathematical model to demonstrate a weight reduction in the first third party's brake caliper that was at least theoretically possible while maintaining the desired deflection value (i.e., not exceeding that of the cast iron version of the brake caliper).

After September 28, 1999, but prior to September 28, 2000, 3M offered to produce for the first third party, on a best efforts basis, two prototype aluminum versions of one of such first third party's cast iron prototype brake calipers reinforced with Nextel™ 601 Ceramic Oxide Fibers at $10,000 per brake caliper. After several revisions of 3M's offer, the first third party submitted a purchase order to 3M for eight prototype aluminum versions of such third party's cast iron brake calipers reinforced with Nextel™ 610 Ceramic Oxide Fibers at price of $2,500 per prototype brake caliper.

Subsequent to the above-referenced purchase order, but prior to September 28, 2000, 3M and the first and second third parties began assessing the abilities of various third party casters to be considered as production casters for aluminum brake calipers reinforced with Nextel™ 610 Ceramic Oxide Fibers.

Subsequent to the above-referenced purchase order, 3M met with a third third party to discuss 3M's concept of using chopped fibers to support and position Nextel™ 610 continuous fiber through the casting process for the brake calipers.

In April, 2000 brake calipers were cast of molten aluminum using Nextel™ 610 Ceramic Oxide Fibers supported by chopped fiber in porous ceramic preforms and these were delivered in May, 2000 to the first third party. These calipers failed a burst test conducted by the second third party, however, they were not designed to meet this test.

In June, 2000 brake calipers were cast that met the deflection target that included at least one embodiment of a ceramic preform according to claim 1 and/or 27 of the application containing Nextel™ 610 Ceramic Oxide Fibers. The preform was prepared according to the method of claim 18, claim 40 and/or claim 53. The brake caliper was a metal matrix composite article according to claims 63 and/or 93.

Should a First Office Action on the merits be mailed prior to the filing of this Disclosure Statement, please charge the requisite $180.00 fee (pursuant to 37 C.F.R. §§ 1.97(c) and 1.17(p)) to Deposit Account No. 13-3723.

Respectfully submitted,

December 18, 2002
Date

By: [signature]
Gregory D. Allen, Reg. No.: 35,048
Telephone No.: 651-736-0641

Office of Intellectual Property Counsel
3M Innovative Properties Company
Facsimile No.: 651-736-3833

CLIENT PRIVATE

Exhibit A

SRI International

Final Report • September 1992
SRI Project 3505

U.S. MARKET STUDY FOR CONTINUOUS FIBER METAL MATRIX COMPOSITIES

Prepared for:

3M METAL MATRIX COMPOSITES PROGRAM
3M Center Building 60
St. Paul, Minnesota 55120

Prepared by:

Peter Schwarzkopf
Manager
Advanced Materials Practice

Dirk Zwemer
Senior Consultant
Health and Performance Chemicals Center

Approved:

Philippe A. Michelon, Vice President
Process Industries Division

333 Ravenswood Avenue • Menlo Park, CA 94025-3493 • (415) 326-6200 • FAX: (415) 326-5512 • Telex: 334486

CLIENT PRIVATE

CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

INTRODUCTION

Background

In 1989, the U.S. Congress approved the initial funding for the DARPA/3M Continuous Fiber Metal Matrix Composite (CFMMC) Model Factory Program in a consortium uniting the capabilities of 3M, private and government research facilities, and key prospective CFMMC end user customers. With integrated product development to speed qualification in select military aerospace components, the program has three objectives:

- To develop CFMMC technology
- To develop low-cost manufacturing methods for CFMMCs
- To accelerate the commercialization of CFMMCs.

A basic premise for the CFMMC Model Factory is that initial investment in low-cost manufacturing technology in a commercial-scale plant for advanced military aerospace systems would ultimately lead to economies of scale which made CFMMC price-performance attractive to civilian aircraft designers. Further economies of scale could also lead to even broader applications in other transportation, industrial, and consumer markets.

While the initial premise for a "dual-use" CFMMC Model Factory was appropriate at the time of its 1989 creation, the enormous geopolitical reconfiguration that has occurred since requires a fresh analysis of the military-to-civilian market assumptions used to justify any projection of future CFMMC commercialization. Because of this, 3M/DARPA commissioned SRI to update its understanding of the CFMMC market and how the 3M/DARPA Model Factory monotape technology currently fits into that market. This report contains the results of SRI's market research and our analysis of the market data, conclusions, and recommendations.

Objectives and Scope

The primary objectives for SRI's study were:

- To analyze the U.S. market for fiber-reinforced metal matrix composites, with special emphasis on CFMMCs
- To identify critical success factors for 3M's entry into the CFMMC marketplace, including the best opportunities and competitive positioning.

SRI derived an overall CFMMC market description from four specific U.S. market segments: (1) military and civilian aerospace; (2) automotive; (3) recreational/sporting goods; (4) general industrial goods. Within each market segment, SRI acquired information on key applications and related issues, including:

- Timing of CFMMC adoption
- Performance requirements
- Cost constraints
- Size of market by volume of CFMMC material
- Competitive technologies
- Testing and qualification requirements
- Appropriate 3M market introduction strategies.

SRI restricted the geographic scope of the market study to the U.S. However, we also used some information on international activities as available from existing SRI sources to gain added perspective on MMC technology, competition, and potential commercialization strategy.

Methodology

SRI conducted the study through performance of six tasks:

Task 1. MMC Market Overview

Task 2. Competitive Analysis

Tasks 3 to 6. Market Segment Interviews

Management and Staffing

The study was performed in the Health and Performance Chemicals Center, Process Industries Division, Business and Policy Group. The project supervisor was Ms. Jeanie Ayers, Center Director. The project leader was Dr. Peter Schwarzkopf, Manager, Advanced Materials Practice, Health and Performance Chemicals Center. The SRI study team members included:

Mr. Brock Hinzmann, Program Manager, Business Intelligence Center, Business and Policy Group—MMC market overview; aerospace market interviews

Dr. Sylvia Johnson, Manager, Ceramics Program, Materials Research Laboratory, Sciences Group—technology overview and analysis

Mr. Larry Rinek, Senior Consultant, Manufacturing Industries Practice, Business and Policy Group—general industrial and recreational market interviews; competitive analysis

Mr. Kumail Tyebjee, Consultant, Automotive Industries Practice, Business and Policy Group—automotive market interviews; competitive analysis.

Mr. Patrick Wray, Industry Analyst, Business Intelligence Center, Business and Policy Group—MMC market overview; aerospace market interviews

Dr. Dirk Zwemer, Senior Consultant, Health and Performance Chemicals Center, Business and Policy Group—aerospace market interviews; competitive analysis.

CONCLUSIONS

- Titanium-matrix composites (TMCs) are the driving force behind the adoption and ultimate commercialization of CFMMCs.
- Initial end uses for TMCs will be in military aircraft (first in engines, then airframes) and space vehicles, but will be contingent upon the future funding and scope of such programs as NASP, AX, MRF, and HSCT. There is little opportunity for CFMMC applications in retrofit or for systems late in the design stage.
- We estimate that by the year 2004, the potential market for TMCs will be—in a best-case forecast—51,000 pounds. Depending upon the future of X30, AX, and MRF, the best single opportunity for future TMC demand growth in the period 2005 to 2012 will be in HSCT engine components.
- The adoption of CFMMCs in commercial aircraft, industrial applications, and recreational equipment will follow military use and will be based on such factors as cost reduction, risk reduction, standardization and design rules, and an established manufacturing capability.
- The 3M/DARPA Model Factory program goal of reducing the price of alumina-fiber or other CF-reinforced titanium monotapes to $500-$1,000 per pound will be too high for most commercial aviation and almost all industrial applications.
- The best sources of competitive advantage for the Model Factory alumina-fiber monotape TMC form are in lower cost and potentially improved properties due to a better thermal expansion fiber/matrix match and easier component fabricability. However, the alumina-fiber TMC must first overcome market perceptions that it is a 3M-driven system without a mission, and that it is inferior to silicon carbide fiber TMCs, and there is little end-user incentive to develop comparative performance data.
- The geometry and lower service temperature requirements of landing gear components in fighter retrofit or new-design systems such as NASP and HSCT may better demonstrate the advantages of monotape-related process techniques than engine parts
- The absolute material performance requirement may be ameliorated by engine design, which would improve monotape competitive position. However, this would require a substantial commitment by the engine system designer in concert with other constituencies in the material selection decision process. While SiC-reinforced TMCs are now the preferred aerospace technical option, business considerations of fabricators and assemblers based on producibility, cost, and risk may actually allow a competitive alumina-fiber-reinforced TMC alternative

- A "generic" Model Factory that can treat and process a variety of fibers (regardless of origin) to produce many different product forms (e.g., coated fiber, "Sasheen" tape, prepregs, preforms) would be responsive in meeting potential market needs. Conversely, any single Model Factory CFMMC monotape product —regardless of reinforcement or matrix—will probably not find a total market and set of commercialization opportunities that could justify the requisite future investment.
- Integrated product development involving all the constituencies involved in advanced system development is a prerequisite for acceptance of monotape or other advanced materials. Realistic broader commercialization outcomes will ultimately depend upon satisfying mutual vested business interests of industrial partners that can use Model Factory monotapes to meet that first demand and derivative market demands.
- The present Model Factory industrial coalition seems to be a reasonable starting point for such constituency partnering. However, to be most effective as a basis of monotape technology transfer and commercialization, the coalition must be seen to strongly emphasize cost-effective manufacturing development of specific end-use components based on initial demand created by Federal sponsorship that creates built-in first customers.
- Since the Model Factory will require sponsorship based on strategic—rather than financial—return objectives, any commercialization strategy must appeal both to business considerations of coalition partners—emphasizing such issues as system cost, performance, and marketing—and to U.S. Government defense and competitiveness priorities related to the establishment of a national resource for defense/aerospace advanced materials development.

RECOMMENDATIONS

- Since the aerospace technical decision has already been made in favor of TMC—but the component-supply business decision has not been made—the Model Factory program must seek to establish competitive advantage based on such factors as reduced cost, component processability, and business risk aversion to overcome selectional advantage of existing foil and powder monotape CFMMC technologies.
- Because of the importance of cost-effective component processability to ultimate commercialization prospects of Model Factory monotape, alliances should be sought with organizations that support process development. (While the Model Factory consortium is a starting point, coalition may be a better model in terms of a cooperative venture focused on the development, manufacture, and marketing of complex aerospace/military composite parts.) 3M might also build a strong stable of component fabricators to develop a qualified CFMMC manufacturing infrastructure that can meet assembler needs.

- The Model Factory should be as responsive as possible to unanticipated market needs, and it should be in a position to supply generic fiber-related products in the form of coated fibers, prepregs, preforms, and the like for a wide spectrum of possible future prototype product development efforts in which DoD, DoE, or NASA may be the "first customer."
- 3M should consider integrating other components of its fiber technology (e.g., Nextel, PVD/CVD coatings, fiber placement, web processing, consolidation) to the Model Factory—in a "Fiber-related Business"—both to gain scale economies and to establish a broad proprietary capability for fiber treatment and manufacture of fiber-based products (e.g., metallized fiber, resin-bonded tapes, woven and non-woven preforms and prepregs). These fiber products can be developed by fabricators into a variety of organic and inorganic composite and non-composite components for both aerospace and industrial markets.
- Since the strategic implications of the Model Factory must go beyond even long-term financial return considerations based on potential future market size, 3M should seek alliances and commitments from industrial partners—particularly with component fabricators and system designer-assemblers—that have their own vested business interest in successful proprietary commercialization of the monotape technology in their products.
- 3M senior corporate management should deal directly with equivalent-level decision makers in Government and at potential industrial partners to demonstrate a 3M commitment to a CFMMC and related fiber businesses and solicit corresponding commitments from Government and industrial partners, in order to make explicit the strategic reasons for pursuing the Model Factory program. A parallel public relations program appealing to management and technical personnel might support this effort.
- In commercializing the Model Factory technology, 3M should organize itself around business activities rather than product technologies:
  - The Model Factory, manufacturing a variety of treated-fiber, CFMMC, or MMC tapes, preforms, "prepregs, " and other products
  - A 3M "Fiber-related Business," integrating all 3M technical, manufacturing, and marketing competences such as in fiber production, treatment, placement, and metal-, ceramic, and polymer-matrix composites.

NEXT STEPS

- Acquire information from senior management of the key players most affected by the 3M/DARPA Model Factory monotape technology; namely, component fabricators and system designer-assemblers, to determine the business benefits of mutually exploiting the competitive advantages of 3M/DARPA monotape technology in a strategic alliance.

Buy Textron Fiber

- Assess 3M corporate technical and business core competencies, incorporating all aspects of 3M's fibers and related product technologies, that create special market value and competitiveness for a 3M "Fiber-related Business" together with the Model Factory.
- Identify synergistic coalitions with outside industrial partners within the framework of the Model Factory and the 3M Fiber-related Business as the basis for proposals to Federal agencies for the development and manufacturing of critical—targeted—military/aerospace components.
- Conduct an innovation search to determine potential opportunities for Model Factory monotape and related 3M Fiber-related Business product forms and functionalities meeting as-yet-unanticipated aerospace and industrial market needs.

INTRODUCTION

BACKGROUND

In 1989, the U.S. Congress approved the initial funding for the 3M/Defense Advanced Research Project Agency (DARPA) Continuous Fiber Metal Matrix Composite (CFMMC) Model Factory Program. The CFMMC Model Factory Program was conceived to develop the technology and commercial manufacturing base to make available next generation composite materials required for the airframes and engines in future military and civilian aerospace systems. In a consortium uniting the capabilities of 3M, private and government research facilities, and key prospective CFMMC end user customers, the program intends to integrate product development and speed qualification in select military aerospace components. As such, the program has three objectives:

- To develop CFMMCs
- To develop low-cost manufacturing methods for CFMMCs
- To accelerate the commercialization of CFMMCs.

A basic premise for the CFMMC Model Factory is that initial investment in low-cost manufacturing technology in a commercial-scale plant—enabling initial CFMMC applications in advanced military aerospace systems—would ultimately lead to economies of scale which made CFMMC price-performance attractive to civilian aircraft designers. A goal of less than $1000/pound was targeted, a level anticipated to be attractive in the civilian aircraft market. Based on a versatile monotape manufacturing approach which is adaptable to a variety of fiber/matrix composite combinations, derivative CFMMC applications accruing further economies of scale would also lead to even broader applications in other transportation, industrial, and consumer markets.

While the initial premise for a "dual-use" CFMMC Model Factory was appropriate at the time of its 1989 creation, the enormous geopolitical reconfiguration that has occurred since requires a fresh analysis of the military-to-civilian market assumptions used to justify any projection of future CFMMC commercialization. For the U.S. military, these changes impact such factors as the strategic uncertainty with respect to the stability of the Commonwealth of Independent States (CIS), Third-World arms build-up, and response to future Third-World political crises and conflicts.

In addition to strategic U.S. military issues, there are fundamental economic drivers. For example, U.S domestic commercial manufacturers must be globally competitive as suppliers and exporters of aircraft and weapon systems, as well as civilian products requiring advanced materials. As a result, the requirements and justification for individual advanced materials in components for next-generation military aerospace systems programs.will change with the shifted focus of future U.S. domestic and foreign policies.

Framed by new international political realities, Department of Defense (DoD) and congressional support of weapons-related advanced materials development programs will presumably be altered as to be consistent with realigned domestic U.S. political and economic priorities. Therefore, the previously forecast need and timing for CFMMCs will change according to the new size and direction of military spending. This change will especially affect the assumed dual-use CFMMC Model Factory utility, probably downsizing the previously expected base of "first customer" military market requirements and the resulting CFMCC economies of scale that could support and lead to eventual commercial exploitation.

Because of this changing environment, 3M/DARPA commissioned SRI to update its understanding of both the military and commercial CFMMC markets and how the 3M/DARPA Model Factory monotape technology currently fits into those markets. This report contains the results of SRI's market research and analysis of the market data, leading to our conclusions and recommendations for future exploitation of Model Factory technology.

OBJECTIVES

The primary objectives for SRI's study were twofold:

- To analyze the U.S. market for fiber-reinforced metal matrix composites (MMCs), with special emphasis on on continuous-fiber-reinforced metal matrix composites (CFMMCs)
- To identify critical success factors for 3M's entry into the CFMMC marketplace, including the best opportunities and competitive positioning.

SCOPE

SRI derived an overall CFMMC market description from four specific U.S. market segments:

- Military and civilian aerospace
- Automotive
- Recreational/sporting goods
- General industrial goods.

Within each market segment, SRI acquired information on key applications and related issues, including:

- Timing of CFMMC adoption
- Performance requirements
- Cost constraints
- Size of market by volume of CFMMC material
- Competitive technologies
- Testing and qualification requirements
- Appropriate 3M market introduction strategies.

SRI restricted the geographic scope of the market study to the U.S. However, we also used some information on international activities as available from existing SRI sources to gain added perspective on MMC technology, competition, and potential commercialization strategy.

METHODOLOGY

SRI conducted the study through performance of six tasks:

Task 1. MMC Market Overview

Primarily using SRI's existing MMC market databases and other information resources, SRI estimated:

- The overall and segment size of domestic U.S MMC markets
- The historical and projected market growth (1990 to 2010)
- Current and future market growth trends and driving forces
- Markets by MMC matrix metal and reinforcement type.

Task 2. Competitive Analysis

Based on the market overview and the results of interviews with other materials developers and potential end-user customers (see Tasks 3 to 6), SRI assessed the commercial competitiveness of the 3M technology with respect to:

- Discontinuous reinforced MMCs
- Other fibers and matrix metals
- Other materials (e.g.: metal alloys; ceramics; polymers)
- Product form (e.g.: coated fiber; monotape; preforms)
- Component process technology.

Tasks 3 to 6. Market Segment Interviews

SRI conducted field and telephone interviews with individuals known by 3M and/or SRI to be especially knowledgeable in the area of MMCs, competitive materials, and end-use applications in organizations representing each of the four major market segments. By task, these included, respectively: aerospace; automotive; recreational goods; industrial goods. Following a standardized interview guide, SRI addressed the following issues in the interviews:

- Key MMC applications in the segment
- Timing of the applications
- Cost/performance requirements
- Price points and demand-price elasticity
- Competitive materials or design technology
- Qualification requirements and timing

- Suggested 3M market introduction strategy.

MANAGEMENT AND STAFFING

The study was performed in the Health and Performance Chemicals Center, Process Industries Division, Business and Policy Group. The project supervisor, responsible for overseeing the direction and quality of the work, was Ms. Jeanie Ayers, Center Director. The project leader, responsible for the day-to-day management and a prime contributor to the analysis and other key areas of the study, was Dr. Peter Schwarzkopf, Manager, Advanced Materials Practice, Health and Performance Chemicals Center. The SRI study team, listed with their principal individual responsibilities, included:

> Mr. Brock Hinzmann, Program Manager, Business Intelligence Center, Business and Policy Group—MMC market overview; aerospace market interviews
>
> Dr. Sylvia Johnson, Manager, Ceramics Program, Materials Research Laboratory, Sciences Group—technology overview and analysis
>
> Mr. Larry Rinek, Senior Consultant, Manufacturing Industries Practice, Business and Policy Group—general industrial and recreational market interviews; competitive analysis
>
> Mr. Kumail Tyebjee, Consultant, Automotive Industries Practice, Business and Policy Group—automotive market interviews; competitive analysis.
>
> Mr. Patrick Wray, Industry Analyst, Business Intelligence Center, Business and Policy Group—MMC market overview; aerospace market interviews
>
> Dr. Dirk Zwemer, Senior Consultant, Health and Performance Chemicals Center, Business and Policy Group—aerospace market interviews; competitive analysis.

been the sizeable investment already made in PMC technology and manufacturing capacity, which should be used preferentially to justify the sunk cost of the investment.

For higher-temperature applications (e.g. 1200°F in aircraft engines), competitive materials include monolithic and fiber-reinforced superalloys, monolithic and fiber-reinforced intermetallic alloys, and monolithic and fiber-reinforced ceramics. Currently, superalloys cannot offer the performance improvements required because of their high density. Intermetallics are useable to higher temperatures than TMC, but weaker at the temperatures where TMC can be used. The better performing are also more brittle and difficult to process. Ceramics are considered far less technically mature than CFMMCs, but they would be applied at higher temperatures.

Competitive technologies also includes alternate design approaches. In the HSCT engine, for example, the engine design chosen will affect whether TMC is required in the exhaust nozzle section, which will have a major impact on the volume of TMC consumed (see Exhibit I). Historically, in many aerospace programs, there has been a bias preferring design solutions that eliminated the need for new higher-performance materials. However, end-use system performance can be compromised by the application of older state-of-the-art. materials.

Testing and Qualification

Many early new-materials adopters in the aerospace industry, such as system prime contractors or development consortia, have done their own testing and qualification. Later followers, such as component fabricators and subcontractors, will require extensive documentation, such as A and B "allowables", and contained in such accepted aerospace material standards and specifications as Mil Handbook 5 (or 17). However, it appears unlikely that any aerospace companies would be pioneers—even if the CFMMC properties database were available. Because of the many possible variations in fiber orientation and manufacturing process, both military system sponsors and their contractors agree that extensive mechanical testing, reliability evaluation, and failure analysis will have to be performed on each new CFMMC component. The consensus among interviewees was that total qualification times are likely to run 1-3 years for each CFMMC-containing component.

AUTOMOTIVE APPLICATIONS

discontinuously reinforced aluminas

Background

The principal development targets for (CF)MMCs in the automotive area are related to engine applications, especially in moving parts. Pistons, particularly for fuel-efficient low-particulate-emission diesel engines, have received the greatest attention. Toyota announced the first development in 1983. Automotive MMCs are typically DRAs, either squeeze-cast with chopped-fiber preforms or powder-metallurgy aluminum with particulate reinforcement. Currently, at least 14 companies worldwide have reported development of MMC pistons. Other mass-sensitive moving automotive components are also development targets. For example, Honda produced (and since discontinued) a novel cast-aluminum stainless-steel-fiber-reinforced connecting rod for their specialty-market 1.1-liter City engine.

Non-moving MMC engine parts can reduce weight, increase thin-section hot strength, and improve thermal conductivity (viz. over iron) to allow higher operating temperature. For example, since 1989, Honda has manufactured (now at a rate of 70,000 annually) die-cast

aluminum engine blocks with a chopped alumina/carbon fiber preform reinforcement around the cylinder bores. The block configuration, used in the Prelude ("States") Si, eliminated the need for conventional cast-in iron cylinder liners, and, with 100cc greater displacement the Si engine has significantly greater torque than the base block from which it was derived. Similarly, Peugeot is fleet testing a squeeze-cast alumina-fiber(Saffil)-reinforced aluminum MMC insert for the cylinder head of a high-performance 2.1-liter turbocharged diesel. The MMC-based head design allows the engine to run hotter, burning fuel more efficiently and cleanly, and making more energy available for the turbocharger.

Other moving and non-moving automotive engine components under development include:

- Wrist pins
- Rocker arms
- Intake valves
- Turbocharger impellors
- Timing sprockets and accessory pulleys
- Oil pump and crankcase housings.

Outside the engine, silicon carbide-reinforced aluminum MMCs have been tested for disk brake calipers and rotors. Conceivably, MMCs may be also applied in future space frames, bumpers, and suspension components for ultralight energy-efficient vehicles.

Interviews

A digest of interview results from the U.S. automotive industry is presented in Table 2. The full interview notes are provided in Appendix A.

Key Applications

The U.S. automotive industry is actively engaged in developing applications for discontinuously-reinforced aluminum (DRA). On the other hand, there are no major programs in CFMMCs and all projections of CFMMC consumption and timing are highly speculative. At current CFMMC prices, the Big 3 automakers do not even consider them viable candidates for R&D, much less production.

The initial applications for DRA are brake systems, including rotors and calipers, and driveshafts. Currently, DRA brake rotors can only be used for the rear wheels, because hot spots on front wheel brakes exceed the temperature rating for DRA. Dural (Alcan) appears to be the principal supplier involved, but Lanxide is also active in this market. These applications are being pursued by all of the Big 3 and by the principal brake system suppliers, including Allied-Signal, Rockwell, and Mahle.

The use of CFMMC materials is likely to consist of selective reinforcement of pressure-cast aluminum castings, particularly in small high-performance engines. The model is the Honda application, and this is discussed below as a case study for new material adoption. Like Honda, U.S. automakers can gain experience with both discontinuous and continuous fiber preforms. It should be noted that, from the perspective of the materials supplier, this application would represent a possible fibers-related preform business, not an MMC business, *per se*.

Table 2 Interview Digest - Automotive

Key Applications	Critical Decision Factors
All automotive MMC applications described are for particulate-reinforced MMCs with aluminum matrix. One CFMMC program (alumina/aluminum connecting rods) between Chrysler and DuPont in the mid-1980's was dropped when material cost could not be brought below hundreds of dollars per pound.	Automobile companies are, first and foremost, cost-driven in their choice of materials. Other industry drivers are meeting mandated fuel efficiency, emissions, and safety rules. The third set of drivers is styling and performance, which allow the manufacturer to advertise a distinct identity for their vehicle.
Brake rotors, brake calipers - first MMC products, based on Duralcan DRA, to be introduced 1994-1997, rear rotors initially, roughly 7-8 lbs per vehicle	Automobile assemblers are extremely risk-averse. Both process and material must be fully developed before they will be considered for production. Manufacturing capacity must be in place before auto companies will commit to purchase. Burden is on material and component companies to overcome entry barriers.
Driveshafts, rear wheel drive propeller shafts and casings for rear axle - 1994-1995 at earliest	MMC components can provide performance improvements or weight reduction. Performance improvements are generally more important on smaller cars with weaker engines. Weight reduction is more critical on large cars. Typically, new product introductions are on large, luxury cars.
Pistons (crown and ring groove), connecting rods, valves, cylinder liners, cylinder heads/inserts - done in Japan and Europe, but no current plans in U.S. for production vehicles, possible introduction 1998-2001	Environmental, safety, and health issues are increasingly important drivers. Recyclability of MMCs is a major concern as auto companies are given responsibility for recycling/reuse. Health of manufacturing workers working with discontinuous fibers/whiskers/particulates is another concern.
Other possibilities: structural oil pans, rocker arms, suspension control arms, torque links, suspension control arms, bearing cap ladders, steering knuckles, brackets, bearings, pump and gear box housings, gears, wheels.	

Table 2 Interview Digest - Automotive (continued)

Performance Factors	Qualification and Testing Issues
Brake rotor and caliper - wear resistance, low density, temperature resistance, modulus. One impetus for DRA brake rotors is weight reduction. Second is reduction of NVH (noise, vibration, and harshness). Currently, DRA cannot be used on front brake rotors because of localized hot spots that exceed material temperature capability.	Material properties databases and history of use are considered extremely important by design engineers, less so by researchers. Extensive fatigue testing and failure analysis is a prerequisite for use in production.
Piston - fatigue resistance, wear resistance, creep, temperature resistance. Moving the piston ring closer to the crown decreases emissions, but would require reinforcement around crown.	Automobile companies will test new materials/components 2-3 years before comitting for production. Concept to first production vehicle is minimum 5 years.
Driveshafts - specific modulus, torque strength, fatigue resistance, reduced number of parts	Road testing of new components at Ford requires 5 vehicles for 50,000 miles.
Connecting rods - specific modulus and strength, coefficient of thermal expansion. Reduced reciprocating mass increases engine acceleration, reduces vibration.	
Ability to withstand harsh automotive environment without corrosion is important for all applications.	

Table 2 Interview Digest - Automotive (concluded)

Cost Issues	Manufacturing Issues
All new materials are subject to a thorough cost-benefit analysis. Systems cost (cost to manufacture the vehicle) is the most important consideration, but all makers indicate that cost per pound is also an issue. Lifecycle costs are generally not considered, although cost of warranty repairs may be an issue in special cases. Maximum cost per pound targets were given in the range of $5-25. CFMMCs at hundreds of dollars per pound would not even be considered. The general belief is that there is no benefit that would allow use of such expensive materials. Current cost targets for DRA connecting rods, $2/lb; pistons, $1.25/lb; cylinder liners, $4 each, installed.	Automobile companies fabricate some parts where they believe they have significant proprietary technology (e.g Ford with engines) and would buy raw materials, such as a ceramic fiber preform. Other parts, such as brake rotors, they would purchase as components or complete systems from subcontractors. General trend is toward increased outsourcing. MMCs are perceived to require new manufacturing facilities (e.g. they cannot be stamped like aluminum and iron). Manufacturers do not believe that reliable, highly reproducible manufacturing methods for MMCs exist.

Competitive Materials	Other Comments
Traditional automobile materials are cast iron, steels, and aluminum alloys. Titanium for valves is used in racing cars. PMCs are being widely investigated by all the manufacturers. Cost and damage resistance are still concerns. In some applications, particularly driveshafts, they are competing with MMCs.	There is a strong need for new materials suppliers to have a good understanding of how the automobile industry operates and to "speak automotive language". Evidently, Duralcan and other new materials suppliers have not always met this expectation.

Timing

DRA brake rotors and driveshafts are scheduled for introduction in the 1994-1997 model years. Initial DRA applications will be in larger luxury and high-performance sports models, and—following typical Detroit operating procedure—will migrate downwards to intermediates in 5-10 years. Other applications, such as steering system, suspension, and gasoline and diesel engine components (e.g. connecting rods, blocks, heads, and pistons), could follow within a few years.

Based on the current status of U.S. automobile engine development activity, CFMMC applications in U.S. engines are unlikely to appear before 2000. However, this may be accelerated pending imposition of stricter fuel economy (e.g., CAFE) and exhaust emission standards,. This could stimulate a sense of urgency in rethinking engine design and associated component development and cost-effective manufacture. The material-performance trade-offs between ferrous, DRA, and hypereutectic aluminum pistons for next-generation engines is a case in point.

Performance

In the case of brake rotors, the performance drivers in the adoption of DRA are light weight, high specific strength and modulus, wear and temperature resistance, and acoustic damping properties. Replacing the current cast iron rear brake rotors with DRA will reduce vehicle weight by 5-6 pounds. Even more attractive to automobile manufacturers, DRA brake rotors produce a lower level of "NVH" (noise, vibration, and harshness) and are expected to reduce the cost of warranty repairs required to "fix" noisy brakes by several million dollars per year.

The drivers for driveshaft applications are high specific stiffness and improved fatigue resistance. The stiffer material will allow driveshafts to be made in one section rather than the current two, leading to cost reductions in fabrication and assembly.

Engine applications cover a range of components where selective reinforcement of aluminum is beneficial. Reinforced cylinder liners allow larger diameter cylinders in the same size engine block. Reinforcement of the piston ring groove—especially as the top-ring groove moves higher—can lead to reduced emissions and greater fuel efficiency. Reduction of reciprocating mass in pistons, valves, connecting rods, and other moving engine components can benefit fuel efficiency, acceleration, and NVH.

Cost

The automotive industry is extremely cost-sensitive. Although <u>system cost</u> (cost of materials plus cost of fabrication and assembly less cost savings in other parts of the system) is the primary measure, <u>price-per-pound</u> is also highly visible. If price-per-pound is significantly greater than current materials (which are generally less than $2 per pound), there is significant industry skepticism that system-cost considerations can ever justify adopting the new material.

Dollars per pound weight saved (DPPWS) is as important in automobile design studies as in aerospace, but the values are much less. For brake rotors, the DPPWS value was $1.50, compared to hundreds of dollars in aerospace.

With respect to ceramic fibers, cost per pound requirements may be recalculated due to the fact that a small amount of fibers may effectively reinforce a much larger amount of metal. Still, widespread use of alumina ceramic fiber is likely to require reducing fiber prices to below $20 per pound (see Exhibit II and following section).

Volumes and Price Sensitivity

The principal MMC markets in the U.S. automotive industry over the next 20 years are for DRA and for alumina fiber used in preforms for localized reinforcement of aluminum castings. Projections of volume for both products, under optimistic and pessimistic scenarios, are given in Exhibit II. In the best-case scenario, DRA will be introduced in the mid-1990's and become a standard material (approximately 10 pounds per vehicle) by 2012. In this scenario, preforms made from continuous alumina fiber will be in production vehicles by the year 2000.

These scenarios are highly price-sensitive. Significantly higher fiber prices than those projected in the optimistic scenario will both delay the development of interest by the automobile manufacturers in the technology and reduce the range of applications for which fiber will be used. DRAs face similar price elasticity curves.

Competitive Technologies

For the component applications in which MMCs—particularly DRAs—would compete,.the primary automotive materials will remain wrought and cast ferrous and aluminum alloys. These materials are extremely inexpensive relative to current MMCs, processable by the techniques and equipment in the installed automotive component manufacturing base, and have a long history of successful applications in this highly conservative and risk-averse industry.

Competition by other "advanced" materials for these potential MMC applications is relatively limited. For example, there are currently hybrid driveshafts consisting of a PMC sheath over an aluminum core. Generally, PMCs are not considered for elevated-temperature underhood and brake system applications. Furthermore, problems arise in mating highly-stressed fatigue-prone PMC components to metallic fittings (e.g., the universal joint). Ceramics and ceramic-matrix composites are potentially major materials for engines because of their wear resistance and ability to operate at much higher temperatures. Industry consensus is that ceramic-intensive engines (e.g., adiabatic diesels, gas turbines) should become commercially important by the middle of the next decade (2000-2010).

Testing and Qualification

Adoption of new materials into production vehicles is a 5- to 6-year process—from engineering concept to the first vehicle off the line. Material testing and development generally takes 2-3 years, including extensive road testing in demonstration cars. Design lead time for use in a specific new vehicle can require an additional 2-3 years. National Highway/Transportation Safety Administration (NHTSA) approval may be required for components in such highly failure-sensitive systems as brakes and steering, but such approval is generally not a rate-limiting step in new product introduction.

Automotive Applications

Interviews:

CFMMC Project

Interviewee:

Job Title:

Organization:

Address:

Date: 6/23/92

Reporter: Kumail Tyebjee

Field Interview

Phone:

Fax:

Description of Application Existing___ Envisioned X

Brake rotors and drums, brake calipers

Market Size and Timing

1995-96 intro of MMC (Duralcan) brake rotor. Average weight of 3.6 lbs as compared to 9.7 lbs cast iron rotor.

Factors Driving Buying Decision

Weight savings, which leads in turn to greater fuel efficiency. Also, weight savings can possibly allow lighter suspension system, because sprung weight is less.

Performance/Qualification

Needs to pass reliability/durability tests. Unfortunately, current material is unsuitable for front rotors where temperatures are higher (because FWD cars use front brakes more than rear brakes). Therefore, current application in rear rotors only. Material performance database is critical, as is history of use.

Cost Factors

Duralcan MMC rotor will cost about $20 versus $ 12 to $15 for cast iron. The OEMs will allow material cost increases of $1.50 per pound for every pound of weight savings. In the case of rotor, the weight savings is about 6 lbs, which equates to about $9 more in allowable cost, using this thumb-rule. Therefore, the Duralcan MMC is competitive.

However, one must not overlook the total system cost for a new material such as MMC.

Lifecycle costs are not considered at this time.

Manufacturing

Allied-Signal will purchase the raw material from the supplier and fabricate components for supply to the OEM.

Recyclability is an important consideration, but has not yet been studied to the depth needed for MMC applications.

Competitive Materials

Cast iron, Duralcan, aluminum alloys.

Other Comments

is highly technically-oriented, and has been working on the MMC rotor application since inception.

CFMMC Project

Interviewee:

Job Title:

Organization:
Address:

Date: 6/23/92
Reporter: Kumail Tyebjee
Field Interview

Phone:
Fax:

Description of Application **Existing___** **Envisioned X**

Brake rotors, pistons, connecting rods.

Particulate, discontinuous fiber MMCs (such as Duralcan) are the only ones being considered. Can't see any real application for CFMMCs. One potential might be in the piston area—moving the piston ring closer to the crown, so as to reduce hydrocarbon formation. Might need reinforced piston crown area, a potential application for CFMMCs.

Market Size and Timing

1997 onwards.

Factors Driving Buying Decision

Main factor is cost savings. All other factors, such as weight savings, enhanced performance, NVH reduction, increased stiffness, etc. are far behind

Performance/Qualification

Material performance database and history of use is important to have. This speeds up the technology integration process.

Cost Factors

System cost is considered, not just per pound cost. They are willing to pay higher material costs for useable functions. The materials supplier must be able to demonstrate these functions.

Manufacturing

Would want fabricated components to be supplied by their supplier. Chrysler believes in outsourcing as much as possible.

Competitive Materials

Duralcan, cast iron, aluminum alloys

Other Comments

CFMMCs would never be considered unless their per pound price was in the range of $5 to $20 per pound. Mass usage would depend solely on price.

CFMMC Project

Interviewee:
Job Title:

Organization:
Address:

Date: 6/23/92
Reporter: Kumail Tyebjee
Field Interview

Phone:
Fax:

Description of Application **Existing___** **Envisioned _X**

Brake rotors and drums, brake calipers, engine components (such as pistons, connecting rods, rocker arms, structural oil pans, cylinder heads/inserts, bearing cap ladders, cylinder liners), driveshafts, various bracketry (in the engine, transmission, and chassis area)

Currently, they are not doing any serious research in the MMC area, mainly because the focus of the organization is with current issues *(Ed note: has serious financial problems at present, and its long-term survival is a question mark)*

Market Size and Timing

Late 1990s onwards

Factors Driving Buying Decision

Weight savings
Cost savings
Durability
Performance

Performance/Qualification

Material performance database is not critical, but would be a good starting point. History of use would be interesting. Need to look at failure modes and design techniques more thoroughly.

An area of concern would be the correct orientation of the CF along the required planes. Need to be careful about "kink bands".

Cost Factors

Lifecycle costs are considered. System costing is considered. However, unless per pound cost is less than $25 per pound, its hard to see widespread application of CFMMCs.

Manufacturing

Supplier must provide fabricated components. is a firm believer in outsourcing as much as possible.

Competitive Materials

Duralcan, cast iron, aluminum alloys

Other Comments

had a mid-80s research program with DuPont that was looking at continuous fiber MMCs for conn rods. Unfortunately, that program was shelved because DuPont could not bring cost below $200 per pound. Also, there were serious questions about manufacturing capability. is aware that Mitsui and 3M are two other companies working on CFMMCs.

CFMMC Project

Interviewee:

Job Title:

Organization:

Address:

Date: 6/23/92

Reporter: Kumail Tyebjee

Field Interview

Phone:

Fax:

Description of Application **Existing___** **Envisioned _X**

Brake rotors, pistons, connecting rods

Only particulate MMCs are being considered at this time.

Rear rotor application is better than front for MMC application, mainly because of temperature considerations. That is, Duralcan is unsuitable for FWD vehicles that have front brakes that run hotter (Aluminum is no good over 200C). MMC rotors have improved sound deadening, improved NVH reduction, and better stiffness.

Also looking at fibre-reinforced piston rings (Toyota has had them since 1982). Chrysler would like to apply MMCs in the piston crown area so as to reduce the distance between the rings and the crown, thus reducing hyrdocarbon formation (essential to meeting new CA emissions standards).

Market Size and Timing

1997 onwards.

Factors Driving Buying Decision

Cost savings is the main driver. Other important drivers include emissions reduction (especially for piston application), and fuel efficiency (weight reduction).

Performance/Qualification

The new material must be able to perform under the severe operating requirements of the vehicle. Safety and durability are paramount.

Cost Factors

MMC pistons are about 2 to 5 times the cost of a regular piston. This is too much of a difference. Although system cost is considered, it is hard to justify excessive per pound costs. It would be impossible to justify paying "hundreds of dollars per pound" for CFMMCs. In his opinion, the per pound cost must come below $5 to be considered for "serious" automotive application.

Manufacturing

Supplier must be able to provide fabricated components.

Competitive Materials

Particulate MMCs such as Duralcan.

Other Comments

Materials Engrg is a service group that caters to the various platform engineering groups at Suppliers of materials such as Duralcan try to get the various platforms interested in applications, these platforms then come to Matls Engrg for their expertise, who in turn set up a test and evaluation program with the materials supplier. Matls Engrg has an in-house foundry for fabricating prototypes, and can work with the materials supplier to perform rigorous testing and failure analysis.

CFMMC Project

Interviewee:

Job Title:

Date: 6/23/92

Reporter: Kumail Tyebjee

Field Interview

Organization:

Address:

Phone:

Fax:

Description of Application Existing___ Envisioned X

Engine components (such as pistons, connecting rods, rocker arms, structural oil pans, cylinder heads/inserts, bearing cap ladders, cylinder liners), driveshafts, various bracketry (in the engine, transmission, and chassis area)

Did consider whisker MMC application (DuPont) for the conn rod in the mid-80s. However, program shelved due to high material cost. There still exists potential for using MMCs in the conn rod, however. May want to consider using hybrid MMCs that have continuous fiber along certain planes for better stiffness, and whiskers along the remaining planes.

Cylinder liners are also an interesting application (a la Honda's chopped fiber preform).

Piston crowns are another potential application. A big issue with engine developers is meeting the low emissions standards for the future. One way is to reduce hydrocarbon formation in the first place. It has been shown that if the distance between the top of the piston and the first piston ring is reduced, fewer hydrocarbons are formed. In order to reduce the distance, one needs to strengthen the piston crown area using a new material, and MMCs might be the solution.

Market Size and Timing

Late 1990s

Factors Driving Buying Decision

The objectives of the engine development department are to improve hydrocarbon emissions (in view of new, stricter emissions regulations, especially in CA), reduce NVH, improve specific performance, reduce friction, achieve 100K mile durability, and reduce cost.

To achieve these objectives, the key criteria considered are weight, cost, durability, and performance.

Performance/Qualification

In the previous conn rod program (with DuPont), a major issue was the "kink band", which was caused by the fibers buckling inside the matrix. Therefore, it is important to understand all failure modes of MMCs in the testing/evaluation program.

It would also help if the material supplier "spoke automotive language", and had an understanding of the way the automotive industry operates. *(Ed note: An oblique reference to the fact that the Duralcan people are not completely conversant with the way the automotive industry operates)*

Cost Factors

Lifecycle costs are calculated *(could not find out how they do it)*. Per pound cost is less important than system cost. However, cannot see how CFMMCs would overcome their tremendous cost disparity.

Manufacturing

Some components would be fabricated by outside supplier (such as pistons), whereas other components would be fabricated in-house by

Competitive Materials

Particulate MMCs such as Duralcan.

Other Comments

CFMMC Project

Interviewee:

Job Title:

Organization:

Address:

Date: 6/23/92

Reporter: Kumail Tyebjee

Phone Interview

Phone:

Fax:

Description of Application Existing___ Envisioned _X

Brake rotors, brake calipers, suspension control arms, torque links, steering knuckles

Rotors and calipers are the most likely applications. They are currently looking at particulate MMCs for these applications. For calipers, the increased modulus offered by MMCs is of great interest, although there is the issue of beam strength. In the case of rotors, which are essentially a heat sink, the issue is how to get the heat capacity of the MMCs up to the desired level.

Market Size and Timing

They are currently testing Duralcan rotors and calipers, and if all goes well, they could possibly have them on some vehicles by 1994.

The application is not car line dependent. That is, its not necessary that the MMC components would first appear on luxury cars, then large cars, and so on down the line.

Factors Driving Buying Decision

Cost is the driving issue.

Performance/Qualification

MMC components must go through the same amount of testing as any other new material. They do "a great deal of testing". Although creep resistance and fracture toughness are important, the critical requirement is to have uniformaity from piece to piece. "The automotive industry is not like the aerospace industry where we make a few of a kind. We need to churn out hundreds of thousands of pieces that are all uniform"

Cost Factors

Lifecycle costs are considered only from a check and balance standpoint. That is, they want to make sure there is no great positive or negative deviation from the norm. System cost is the key consideration. However, the industry is highly influenced by per pound costs. Therefore, if the CFMMC is in the range of hundreds of dollars per pound, it is imposiible that it would be ever considered for application, no matter what the systems cost savings.

A cost bogie would be $20 per pound—a figure that would allow the materials supplier to open some doors at the OEM. However, the realistic figure (to get more doors open and gain entry) would probably need to be closer to $10 per pound. Also, the supplier must be able to show (and prove) systems cost savings to the satisfaction of the OEM.

Manufacturing

is flexible in this regard. They would work with the supplier to obtain the material in the form desired.

Competitive Materials
Graphic composite type fibers, E-glass type materials

Other Comments

CFMMC Project

Interviewee:

Job Title:

Organization:

Address:

Date: 6/23/92

Reporter: Kumail Tyebjee

Field Interview

Phone:

Fax:

Description of Application Existing___ Envisioned _X_

Brake rotors and drums, brake calipers, engine components (such as pistons, connecting rods, rocker arms, structural oil pans, cylinder heads/inserts, bearing cap ladders, cylinder liners), driveshafts, various bracketry (in the engine, transmission, and chassis area)

Market Size and Timing

Late 1990s and onwards

Factors Driving Buying Decision

Fuel efficiency (weight reduction) is the driving force for use of MMCs

Performance/Qualification

Need a good material performance database. Also helpful would be some history of use/application. would also need to test about 5 cars with the MMC component in question. They would do 50K mile tests to simulate lifetime use. However, because there is an inherently high risk (of failure) with any new material, they would need to do extensive failure mode analysis and testing. One of the weaknesses of currently-available MMCs (such as Duralcan) is that not enough data is available on failure modes and its effects (FMEA analysis).

Cost Factors

Cannot see how could ever justify paying more than $5 to $20 per pound for MMCs, even considering system cost savings. He does not look at lifecycle costs.

Manufacturing

Would probably want suppliers to fabricate most MMC components.

Recyclability is important. They need to do more investigation regarding recyclability of MMCs.

Competitive Materials

Particulate MMCs such as Duralcan.

Other Comments

Ford utilizes carryover design philosophy, i.e., they take what works and build on that, as opposed to starting from scratch. That is, they are conservative and will not take huge risks. They view the use of MMCs as interesting, but risky. If suppliers can show . how to reduce its risk-exposure, they would be willing to pursue more MMC applications.

CFMMC Project

Interviewee:

Job Title:

Organization:

Address:

Date: 6/23/92

Reporter: Kumail Tyebjee

Field Interview

Phone:

Fax:

Description of Application **Existing___** **Envisioned _X**

Brake rotors and drums, brake calipers, engine components (such as pistons, connecting rods, rocker arms, structural oil pans, cylinder heads/inserts, bearing cap ladders, cylinder liners), driveshafts, various bracketry (in the engine, transmission, and chassis area)

Market Size and Timing

Late 90s onwards

Factors Driving Buying Decision

Fuel efficiency (therefore, weight reduction)

Cost

Need good material performance database—critical requirement

History of use is desirable, otherwise . needs to test and develop its own

Performance/Qualification

Safety is the primary concern. Therefore, risk of failure is the biggest unknown. Any new material must be exhaustively tested and rigorous failure analysis performed. The material must be reliable and perform consistently throughout the lifetime of the car, and proving this lifetime durability is an enormous challenge.

Cost Factors

Cost per pound is the main criterion. System cost is considered. However, do not consider lifecycle costs.

Manufacturing

Material should be available in several forms, depending on application. In some cases, will fabricate their own components, and at other times will want fabricated/finished components to be supplied by their supplier.

Competitive Materials

Discontinuous fiber (particulates) MMCs such as Duralcan.

Other Comments

Looking at whisker MMCs. Haven't seriously considered CFMMCs because of their high cost. Can't imagine if they will ever justify paying "hundreds of dollars per pound" for CFMMCs.

CFMMC Project
Interviewee:
Job Title:

Organization:
Address:

Date: 6/23/92
Reporter: Kumail Tyebjee
Field Interview

Phone:
Fax:

Description of Application Existing___ Envisioned _X_
Brake rotors and drums, brake calipers, engine components (such as pistons, connecting rods, rocker arms, structural oil pans, cylinder heads/inserts, bearing cap ladders, cylinder liners), driveshafts, various bracketry (in the engine, transmission, and chassis area)

Market Size and Timing
Late 90s onwards. Initial applications are in the luxury and larger cars, followed by a trickling-down to the smaller-size cars in later years.

Factors Driving Buying Decision
Cost—most important
Weight savings (leading to fuel savings)
NVH reduction

Performance/Qualification
Need to have thorough failure analysis done.

Cost Factors
Cost savings of $1.50 to $2 per pound is needed. If new material can show this, its worth it to go ahead and pay extra per-pound costs for the new material. Regarding CFMMC, does not believe they will ever consider it unless cost per pound is less than $10 per pound. They do not consider lifecycle costs, although it sounds like a good idea. Total system cost is considered, however, from a realistic standpoint, what people first see is the per pound cost.

Manufacturing
Would probably want supplier to provide finished/fabricated components for certain applications such as brake rotors and so on. In certain engine applications, where Ford has proprietary technology, they may wish to buy the raw material MMCs for in-house fabrication.

Competitive Materials
Duralcan is a strong competitor, especially because it is much more cost-effective. Other competitive materials are traditional cast iron, and aluminum alloys.

Other Comments
Gjostein heads up the entire materials research lab at Ford.

Because MMCs require new manufacturing processes, he feels that there is also some resistance by the metal stamping facilities that currently make iron and aluminum parts, who would be unable to fabricate MMC components without major changes in manufacturing process.

CFMMC Project

Interviewee:

Job Title:

Organization:

Address:

Date: 6/23/92

Reporter: Kumail Tyebjee

Field Interview

Phone:

Fax:

Description of Application Existing___ Envisioned _X

Brake rotors and drums, brake calipers, engine components (such as pistons, connecting rods, rocker arms, structural oil pans, cylinder heads/inserts, bearing cap ladders, cylinder liners), driveshafts, various bracketry (in the engine, transmission, and chassis area), spaceframes

Market Size and Timing

Late 90s to early 2000s. Penetration would occur in usual fashion, i.e., in niche appliocations first, followed by larger cars (where cost is less of an issue, and weight savings more needed), followed by medium-size cars, and so on down the line.

Factors Driving Buying Decision

Cost—is the overriding factor. Total system cost (or savings) is considered, not per pound cost. Also considered is the process savings due to new materials.

Weight savings—is the second most important driver. The major benefit is fuel savings.

Space savings—as cars get smaller and lighter, space optimization becomes critical.

Performance/Qualification

Must meet super-high reliability and durability standards of the automotive industry.

Must have thorough failure analysis documentation.

Cost Factors

CFMMC target cost is absolutely impossible to justify unless it can be demonstrated that considerable savings are possible through process cost reduction, or system cost reduction. At hundreds of dollars per pound, would not even consider testing it for an advanced research project, let alone evaluating it for future production.

Manufacturing

Would want supplier to provide finished, fabricated components.

Competitive Materials

Cast iron, aluminum alloys, Duralcan

Other Comments

This is an advanced engineering group that looks at technology applications 10 years and out. They experiment with advanced technology concepts and features and produce concept cars that showcase leading-edge thinking. They are known for taking radical and creative approaches to automotive technology application, and are known within for their visionary outlook.

CFMMC Project

Interviewee:

Job Title:

Date: 6/23/92

Reporter: Kumail Tyebjee

Field Interview

Organization:

Address:

Phone:

Fax:

Description of Application Existing_X__ Envisioned _X

Brake rotors and drums, brake calipers, engine components (such as pistons, connecting rods, rocker arms, structural oil pans, cylinder heads/inserts, bearing cap ladders, cylinder liners), driveshafts, various brackerry (in the engine, transmission, and chassis area)

Active research program underway for particulate MMC (Duralcan) brake rotor.

Market Size and Timing

Late 90s onwards

Factors Driving Buying Decision

Fuel efficiency thru weight reduction

Performance/Qualification

is currently testing the MMC brake rotor. He has a budget of $0.5 M for this program, but he figures he'll probably spend a total of $1M before the program is over. Their group will do testing for about 2 years before production tooling. After that, it takes another 3 years before Job One. Therefore, concept to Job One is a 5-year cycle. They can reduce this cycle time a little bit by speeding up their testing phase, but the reduction will not be huge.

A good material performance database, extensive history of use/application, material for experimentation—are all things that can help ease MMC technology integration and hopefully reduce the amount of time needed for development and testing.

Failure analysis (FMEA) is critical.

Cost Factors

Per pound cost is the only consideration. Lifecycle costs are not considered. MMC material must be available in the range of $5 to $10 per pound to be competitive. Projected CFMMC costs of hundreds of dollars per pound would be totally unacceptable for volume automotive application.

Manufacturing

Ford is outsourcing more and more, and would probably look to its suppliers for fabricated MMC components.

Recyclability is important. It is felt that MMCs are less recyclable. They need more information from the suppliers to determine recyclability issues.

Competitive Materials
Duralcan and all other particulate-based MMCs that are cheaper

Other Comments
is a leading-edge group within that is involved with advanced engineering concepts 5 to 10 years out in the future.

CFMMC Project

Interviewee:

Job Title:

Date: 6/23/92

Reporter: Kumail Tyebjee

Phone Interview

Organization:
Address:

Phone:
Fax:

Description of Application **Existing___** **Envisioned _X_**

Brake rotors and brake calipers for the electric car

Are currently working on Duralcan rotors. MMCs can provide improved stiffness/weight ratio, which is desirable for a rotor. At this point, they are not sure whether the Duralcan rotors will pass all the tests and prove to be OK for final production.

As regards calipers, he is not sure whether Duralcan will be able to provide the high temperature resistance needed for this application.

Market Size and Timing

1997-99 at the earliest for full production.

Factors Driving Buying Decision

Reduced weight is very important for the electric car program (a lighter vehicle can travel a greater distance on the same battery pack). Cost is the influencing factor.

Performance/Qualification

MMCs must pass all durability tests.

Cost Factors

They consider system cost savings. Do not look art lifecycle costs.

Highly unlikely that CFMMCs would be considered at the projected cost of hundreds of dollars per pound.

Manufacturing

They would want the supplier to provide them with a finished component.

Competitive Materials

Cast iron, aluminum alloys

Other Comments

CFMMC Project

Interviewee:

Job Title:

Organization:
Address:

Date: 6/23/92
Reporter: Kumail Tyebjee
Phone Interview

Phone:
Fax:

Description of Application **Existing___** **Envisioned X**

Driveline applications—specifically rear wheel drive propeller shafts, and casings for rear axles.

The above applications are originally cast iron, so replacing them with MMCs (Duralcan) reduces weight by 66%. The is supplied to in the form of extruded tubes.

Market Size and Timing

1994-95 at the earliest. They are currently developing a business case (to present to management) for use of MMCs, and predict that if all things go according to schedule, they should have MMC driveshafts in production by 1994-5.

Factors Driving Buying Decision

Two key driving factors

1. Weight reduction, which in turn improves fuel efficiency
2. Improved corrosion resistance—no need to paint/finish the MMC driveshaft, thus saving on those costs

An underlying factor that is always implicit in the buying decision is the cost savings possible through use of MMCs. If one cannot show this, it is very difficult to move ahead.

In the case of propeller shaft, using MMCs, it is possible to fabricate a long, single unit shaft, without having to join two units by means of a coupling (as in the case of cast iron).

Performance/Qualification

Thorough testing is a must. Critical speed, durability, fatigue and welding tests are critical. The welding test is a major challenge, because one is bonding a MMC driveshaft to traditional cast iron components.

Cost Factors

Per pound cost is the major consideration for their group, especially because they are mostly driven by weight reduction. System cost is also considered, however, per pound cost has the dominating influence. Lifecycle costs are not really considered. The expectation is that any material/component must have 100-120K mile durability before they even consider it for application.

Does not expect to ever use CFMMCs because of their "outrageously high per pound cost."

Manufacturing

Will work with the supplier in assuring the best approach for supply and manufacture of components. Are flexible in this regard.

Competitive Materials

Cast iron, steel, fibre-reinforced materials

Other Comments
Ali is responsible for advanced engineering projects in the driveline, steering and materials area for Saginaw.

CFMMC Project

Interviewee:

Job Title:

Organization:
Address:

Date: 6/23/92
Reporter: Kumail Tyebjee
Field Interview

Phone:
Fax:

Description of Application Existing___ Envisioned X

Brake rotors and drums, brake calipers, engine components (such as pistons, connecting rods, rocker arms, push-rods, structural oil pans, cylinder heads/inserts, bearing cap ladders, cylinder liners), driveshafts, various bracketry (in the engine, transmission, and chassis area), chassis components such as steering knuckles, complete body shell (spaceframe)

Market Size and Timing

Late 90s onwards.

He sees MMC trend as slow growth. It may turn out that they'll never go into production. he feels that the Japanese are willing to take risks that the US OEMs will not, and that the Japanese are willing to go through the experimentation with MMCs just for the learning experience, something he can't see doing.

Factors Driving Buying Decision

Cost
Reduction of emissions
Fuel economy (weight savings)

Performance/Qualification

Critical to have material performance database, history of use would be helpful, critical to have material for experimentation. . likes to verify the material properties for themselves.

feels that not enough fatigue testing has been done for MMC components. Thorough FMEA analysis is critical, especially because the risk of failure is unknown and the consequences are extremely high.

Cost Factors

Do not consider lifecyle costs. The cost bogie is $10 per pound for volume production. Although system cost is considered in the material evaluation, most people are still influenced by per pound cost. He can't foresee paying hundreds of dollars per pound for any material, except for limited production and niche applications.

Manufacturing

Engine components made from MMCs would probably be made by in-house . divisions, so would want the raw material supplied. In the chassis area, some components such as rotors and knuckles are manufactured in-house, so would want raw material. Other components are outsourced, so their suppliers would provide fabricated components.

Recyclability is very important, and MMC components probably would not help in this regard. The materials supplier needs to demonstrate the extent of recycling possible with MMCs, and needs to study this issue further.

GM feels that a reliable manufacturing method is needed for MMC components—they don't see much evidence of that occurring as yet.

Competitive Materials

Particulate-based MMCs such as Duralcan are the alternatives available today.

Other Comments

There are 10 researchers in the mettalurgy department at a few of whom have been working in the MMC area for several years now. They are very familiar with all the suppliers and are quite aware of what GM's competitors, both here and oveseas, are doing in the MMC area.

CFMMC Project

Interviewee:		Date:	6/23/92
Job Title:		Reporter:	Kumail Tyebjee
		Phone Interview	
Organization:		Phone:	
Address:		Fax:	

Description of Application Existing___ Envisioned X

Pistons, connecting rods, cylinder liners

Particulate MMCs are currently being tested and evaluated for pistons and conn rods. MMCs are being considered for conn rods based on the material's ability to reduce the reciprocating weight by half. In the case of pistons, MMC use can possibly reduce hydrocarbon emissions by about 70%.

Market Size and Timing

1996 at the earliest.

Factors Driving Buying Decision

For pistons, emissions reduction is the driving factor. For conn rods, weight reduction (fuel efficiency) is the driver. And, improved performance is the driver for cylinder liners. In all cases, cost competitiveness (or savings) is the overriding factor that drives the buying decision.

Performance/Qualification

MMCs go through all the usual testing procedures for new materials and components. Of critical importance is fatigue testing and failure analysis.

Cost Factors

Their cost targets are
$2/lb for conn rods
$1.25/lb for pistons
$4 installed per cylinder liner

CFMMC pricing of hundreds of dollars per pound is totally unacceptable. Each conn rod uses about 6 oz of material. If CFMMC was, lets say, $300 per pound, the cost of a CFMMC conn rod would be $100 each for material alone, or $400 per engine. This is excluding all the additional process costs that would be involved.

They do consider systems cost and lifecycle costs, however, per pound cost is the most important. The above cost targets are derived from their calculation of the systems cost savings possible through the use of particulate MMCs.

Manufacturing

They would rather buy the finished component directly from the supplier, but they recognize that this is not always feasible. Therefore, they would want the MMCs supplied in pre-forms such that can infiltrate the material themselves.

Competitive Materials

None mentioned

CFMMC Project

Interviewee:

Job Title:

Organization:
Address:

Date: 6/23/92
Reporter: Kumail Tyebjee
Phone Interview

Phone:
Fax:

Description of Application **Existing**___ **Envisioned** _X

Pistons, connecting rods, valves

They had looked at CFMMC conn rods a few years ago, but MMC supplier could not get the price down, and the program was dropped. They are still interested in CFMMCs for coon rods, however, as long as the prices are reasonable. One issue with CFMMC application is that the fibres are directional and require very precise processes for component fabrication. Thus, they feel that costs could be potentially higher than first apparent.

Titanium valves would have the advantage of being very lightweight and would be highly temp-resistant. The key barrier is their high cost. If CMMCs can help in this regard, they are interested.

Market Size and Timing

Year 2000 onwards. Conn rod application would be more meaningful in 4-cyl cars than 8-cyl cars, so penetration would first take place in small cars, and then work upward.

Factors Driving Buying Decision

Cost is the main driver. They do a thorough cost-benefit analysis. System cost is always considered, not per-pound cost. Lifecycle cost is not considered—can't see what advantage it has.

Performance/Qualification

The material and the process must be fully developed. Many times, a supplier will come to with an innovative new material, but without a full understanding of how to process it efficiently. Therefore, finding an application for this material becomes harder. If the material and process to manufacture components are fully understood, finding an application becomes easier. Of course, the ideal situation would be for the supplier to present the OEM with appropriate and fully developed applications for the new material.

Thorough failure analysis and testing are essential. It takes a minimum of 3 years before any new material can be used in production (assuming the process is already fully developed).

Cost Factors

Although system cost is the consideration, in reality per pound cost plays an influencing role. CFMMCs at hundreds of dollars per pound can never find a place in the automotive industry, which is used to paying a maximum of a few dollars per pound.

Manufacturing

They have flexibility in this regard. Will work with supplier in determining the best supply arrangements for both parties.

Competitive Materials

Standard titanium, complex steel, MMC aluminum fiber whiskers

CFMMC Project

Interviewee:

Job Title:

Organization:
Address:

Date: 6/23/92
Reporter: Kumail Tyebjee
Field Interview

Phone:
Fax:

Description of Application Existing_X__ Envisioned _X
Pistons, conn rods

Are researching CFMMCs. Currently, they are working with particulate MMCs. They were doing work with whisker MMCs, but stopped further development because of carcinogenic concerns with the fibers being utilized.

Market Size and Timing
Late 90s. makes pistons for heavy duty diesel engines in Tennessee. If they saw a good demand for MMC pistons, they could tool up for production of these pistons in their TN plant.

Factors Driving Buying Decision
Emissions reduction

Performance/Qualification
The distance between the top of the piston and the first ring is currently around 6-8 mm. If this distance can be reduced to 2 mm, it would have a dramtic effect in reducing the hydrocarbon formation, thus reducing emissions. One way to achieve this would be to reinforce the top of the piston with MMC material, which is what Mahle is doing.

They'd be concerned with using CFMMCs from the standpoint of potential failure problems. They fibers would probably be abrasive, and fiber particles would need to be filtered so that "they didn't end up all over the engine", causing valve problems and such.

Cost Factors
The price of the MMC piston designed by is about 3 times that of a regular piston. Therefore, they haven't had much success in stirring up interest among the OEMs. Mahle feels that if the price were to be reduced further, the OEMs would become more interested.

Therefore, they cannot see any way of using CFMMCs that cost in the range of hundreds of dollars per pound.

Manufacturing
They would purchase pre-forms of the raw material MMC for fabrication into finished components.

Competitive Materials
None mentioned

Other Comments

Exhibit B

Lightweight Technology for Heavyweight Industries

Continuous fiber reinforced composites offer engineers and designers new freedom in designing high performance parts and components. The ability to construct extremely strong, stiff, and lightweight components has tremendous advantage across a wide range of applications. Industries benefiting from this technology include automotive, high-speed industrial equipment, defense, sports and recreation.

Based on integrated expertise in ceramic fiber manufacturing, materials science, metallurgy, and engineering, 3M has developed a multifaceted metal matrix composite technology platform. This platform provides the means to selectively reinforce aluminum components with 3M™ Nextel™ Ceramic Oxide Fiber, resulting in products with significantly higher strength and stiffness at approximately half the weight of a comparable steel or cast iron part.

The process starts with a detailed analysis of the existing system design constraints. Finite element analysis (FEA) identifies areas in which the maximum benefit is achieved in aluminum using the smallest amount of fiber. The next step identifies the best method to deliver the reinforcing fiber. Finally, selectively reinforced parts are produced using a wide range of traditional casting methods. Mechanical testing then verifies that performance criteria are met.

High Strength Ceramic Fibers

3M uses a sol gel process for producing Nextel™ Ceramic Oxide Fiber. By carefully controlling the process, the resulting high strength continuous oxide fibers are suitable for continuous or cyclical high temperature applications. Nextel Ceramic Oxide Fibers 312, 440 and 550 were developed for industrial applications requiring thermal protection under situations with little or no load. Nextel Ceramic Oxide Fibers 610, 650 and 720 were developed more recently for ceramic, metal and polymer matrix composite applications requiring high strength, low creep at temperature, high stiffness and low chemical reactivity performance. The following table gives an overview of the properties of composite grade Nextel ceramic oxide fibers.

Properties of Nextel™ Ceramic Oxide Fibers

Property	**Units**	**Nextel 610**	**Nextel 650**	**Nextel 720**
Chemical Composition	Wt. %	>99 Al_2O_3	89 Al_2O_3 10 ZrO_2 1 Y_2O_3	85 Al_2O_3 15 SiO_2
Crystal Phases		α-Al_2O_3	α-Al_2O_3 + cubic ZrO_2	α-Al_2O_3 + mullite
Tensile Strength	GPa	3.1	2.8	2.1
Tensile Modulus	GPa	380	360	260
Density	g/cc	3.9	4.1	3.4
Thermal Expansion (25-1000°C)	ppm/°C	8.0	8.0	6.0

Each of the composite grade fibers has a high percentage of alpha alumina in the crystal structure. Nextel Ceramic Fiber 610 is greater than 99% alpha alumina, leading to the highest tensile and compressive strength. Changes in the chemical composition of Nextel Ceramic Fiber 650 and Nextel Ceramic Fiber 720 somewhat reduces the overall strength of the fiber, but improves the creep resistance and even higher temperature capability.

Metal Matrix Composite (MMC) Technology

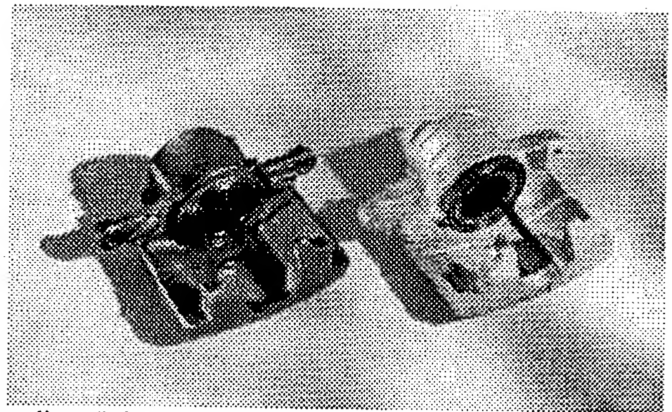
In metal matrix composite construction, the alumina fiber is infiltrated by the matrix metal. Nextel Ceramic Fibers have the ability to work with a wide range of alloys, depending on the requirements desired from the alloy. Generally, an aluminum 2%Cu Alloy MMC gives excellent axial tensile strength (1500 MPa, 220 ksi) with improved physical properties such as coefficient of thermal expansion (CTE) and conductivity. In addition, the material has exceptional axial compression strength (3400MPa, 500 ksi) and superior off-axis mechanical properties such as transverse tensile strength and shear strength. Alloys such as 6061, 319, 354, 356, 357, and 380 have been used and result in products with their own unique properties.

For example, 6061 MMC (Al-Mg-Si alloy) reduces axial tensile strength in order to provide a high compression strength of 4.1 GPa (595 ksi). In general, the resulting component can have properties that are three times the stiffness of aluminum at a density comparable to aluminum, but 50% lighter than steel.

Automotive Applications

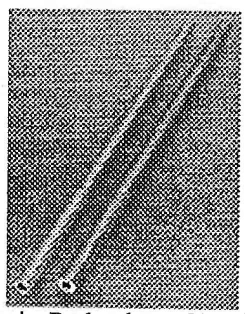
MMC components designed for the automotive market offer lighter weight, stiffer materials with improved damping, leading to less vibration and an improved ride.

A common driving force for automotive component design is the desire to build more fuel-efficient vehicles. Therefore, reducing mass is critical. For example, traditional cast iron brake calipers can weigh 2.7 kilograms (six pounds) each in a small car or up to 13.6 kilograms (thirty pounds) each in a truck. Simply replacing the cast iron with aluminum would reduce the mass, but the available space does not allow the necessary increase in part size required for the aluminum caliper to provide equivalent strength. Composites allow the component to maintain its strength and stiffness without the corresponding increase in part size. In particular, the "bridge" and "ears" sections of the caliper undergo deflection during braking, so a strong and stiff material to reduce the deflection is important. By using finite element analysis, a part may be designed with the same packaging envelope. Thus, the part is selectively reinforced with ceramic fiber to manage the high stress regions in the bridge. The selectively reinforced aluminum caliper, manufactured by traditional casting technology, has the same deflection characteristics as cast iron, coupled with 55% weight savings. Selectively reinforced aluminum brake calipers are currently in the prototype phase of manufacturing.



A traditional cast iron brake caliper (left) and a brake caliper reinforced with 3M Aluminum Matrix Composite (AMC) (right). The AMC brake caliper is virtually the same size but half the weight.

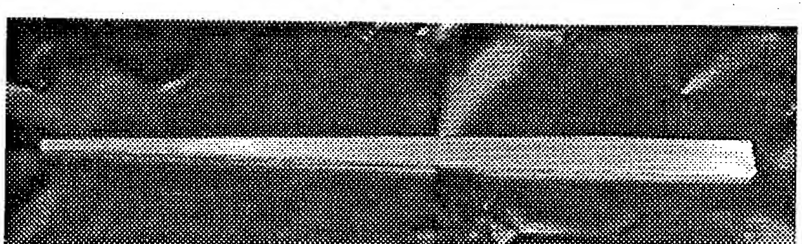
The use of 3M Metal Matrix Composites is not limited to brake calipers. MMC's can also enhance automotive pushrods for high performance engines. 3M™ Aluminum Matrix Composite Pushrods offer up to a 20% stiffness gain, 40-50% weight reduction, greater damping behavior and greater compression strength, compared to a steel pushrod. These property improvements allow gains of 500-1000 rpm that equate to a power gain of about 10 horsepower.



3M Aluminum Matrix Composite Pushrods are 50% lighter and 17% stiffer than steel pushrods.

Industrial Applications

High-speed packing equipment requires components to reciprocate or change direction many times within a given timeframe. To successfully perform these operations, low density, high modulus components are desired. The figure below shows an example of a packing finger, which attaches at the thick section and performs its packaging operation at the thin tip. Bulky aluminum fingers are typically used, but suffer excessive deflection and loss of control when pushed to higher speeds.



Composite Packing Finger, 60 cm long, and unidirectionally reinforced with continuous Nextel™ Ceramic Oxide Fiber 610 along the length of the finger.

Redesign with reinforced aluminum composite provides a packing finger that is three times stiffer, 50% lighter and has better wear resistance of the tip. The result is that the machine can operate 25% faster, which translates into 25% more packaging per unit time. The return on investment is realized almost immediately.

Applications involving high speed rotation benefit from the exceptional properties provided by MMC's. For example, hoop-wound reinforced retainer rings are desireable because of the high tensile strength needed to support large hoop stresses and the low rotating mass. MMC retainer rings are used in motors reaching rotational speed of 100,000 rpm.

MMC's are also used in a variety of applications that benefit from improved compressive strength properties that can be achieved with the composite. For example, compression pins designed for military applications have been shown to have compressive strengths in excess of 4.1 GPa.

Electrical Utility Applications

Wire produced using metal matrix technology is used in overhead power transmission lines. Standard cable uses a steel core to support a pure aluminum jacket. Replacing the steel core with aluminum reinforced composite wire offers a transmission cable with improved conductivity and lower thermal expansion. This dramatically reduces both line sag and leads to increased transmission capacity.

Imagine the Possibilities

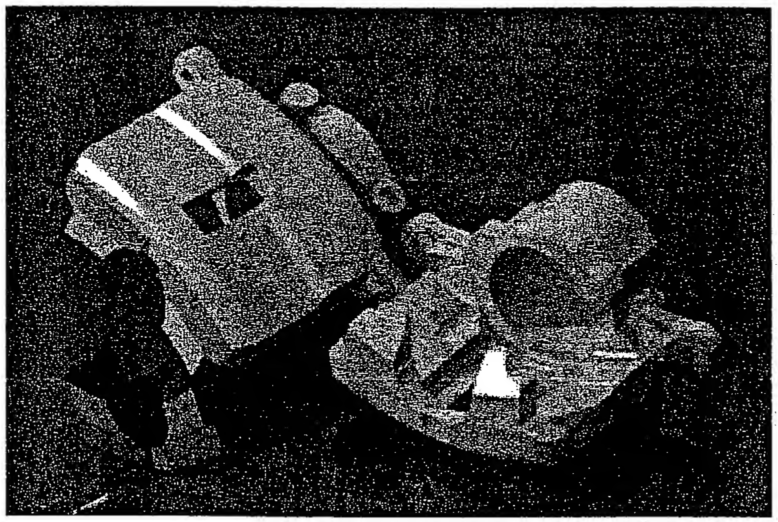
3M Metal Matrix Composites offer high performance material solutions to engineers and end-users worldwide. By combining advanced modeling solutions with traditional casting processes, lighter, stiffer, stronger, and cost efficient components become reality. Utilization of metal matrix composites allow designers to move beyond traditional design constraints to produce innovative, high performance components. The possibilities are endless and can change the basis of competition.

3M Metal Matrix Composites
Building 207-1W-11
St. Paul, MN 55144

Europe: (49) 0 2131 143084
All Other Countries: (+1) 651-733-5168
Email: metalmatrix@mmm.com
Internet: www.3M.com/mmc
www.3M.com/ceramics

Exhibit C

3M Welcomes



Tuesday, September 28, 1999

Metal Matrix Composites Department
3M Company
Mendota Heights, Minnesota

3M ***Innovation***

Curriculum Vitae

Dr. Kamal Amin
Senior Material Science Specialist
3M, Metal Matrix Composites

Dr. Amin has over 25 years experience in R & D and technology development, and applications in both industry and academia. His areas of expertise include sensors, nondestructive technologies, advanced materials characterization and testing, process simulation, alloy development, advanced materials processing and forming, and tribology. He holds 3 patents, has over 50 publications/presentations, several corporate awards for technical achievement, and has chaired several conference sessions and committees.

Research Associate, University Erlangen/Nurnberg
Postdoctor Fellow, Max-Planck Institute
Ph.D., University of California, Berkeley
M.S., Materials Science and Engineering, University of California, Berkeley
B.S., Materials Science and Engienering, University of Cairo

Scott Holloway
Senior Materials Scientist
3M, Metal Matrix Composites

Mr. Holloway joined 3M in 1996 as a Process Engineer. Prior to joining 3M, Mr. Holloway worked as a Mechanical Design Engineer for Behr Heat Transfer Systems, Inc. in Sioux Falls, South Dakota, and Cincinnati Milacron, Inc. in Cincinnati, Ohio. His areas of expertise include matrix alloy development, micromechanics of metal matrix composites, and Finite Element Analysis.

Ph.D. Candidate, Materials Science, University of Cincinnati
M.S., Materials Science, University of Cincinnati
B.S., Mechanical Engineering, University of Texas, Austin

Agenda

9:00	Welcome to 3M	*Frank Loftus*
9:10	Finite Element of Selectively Reinforced PT-44 Caliper	*Scott Holloway*
9:25	NEXTEL™ 610 Ceramic Oxide Fiber - Current Status/Future Work	*Dave Wilson*
10:00	**Tour:** Nextel 610 Ceramic Oxide Fiber Pilot Line	
10:20	Break	
10:30	Continuous Nextel Ceramic Oxide Fiber Reinforced Aluminum and its Alloys	*Colin McCullough*
11:00	Pressure Casting of Caliper Prototypes	*Scott Holloway*
11:15	**Tour:** Pressure Cast Prototype Development Laboratory	
11:30	Lunch/General Discussion	*Axel's River Grille, Mendota*
1:00	Non Destructive Testing of Aluminum Matrix Composites	*Kamal Amin*
1:30	**Tour:** NDT Facility	
2:00	Lightweight Caliper Interest	
2:30	Break	
2:45	Prototype Development Project	*Facilitator - John Skildum*
4:00	From MMCs to HTSC	*Jonathan Storer*
4:30	Wrap-up	

Curriculum Vitae

David Wilson
Research Specialist
3M, Metal Matrix Composites

Mr. Wilson has over 15 years of research and development experience in the synthesis of new ceramic fibers and other novel materials using sol-gel techniques and is the inventor of the NEXTEL™ 610 and 720 Ceramic Oxide Fibers. His experience includes the development of novel fiber precursor formulations and continuous process, testing, and characterization of ceramic fibers at room and elevated temperatures. He holds five patents.

M.S., Ceramic Engineering, University of Illinois, Urbana
B.S., Ceramic Engineering, University of Illinois, Urbana

Curriculum Vitae

Dr. Colin McCullough
Senior Materials Scientist Specialist
3M, Metal Matrix Composites

Dr. McCullough is the lead scientist for the development of aluminum matrix composite material systems and understanding their behavior. Prior to joining 3M, Dr. McCullough worked as a Research Engineer at High Performance Composites Center, Materials Department, University of California at Santa Barbara.

Postdoctoral reasearcher, Materials Research Lab., Brown University
Ph.D, Metallurgy, Leeds University, England
B.Sc, Metallurgy, Leeds University, England

Dr. Jonathan Storer
Staff Scientist
3M, Metal Matrix Composites

Until recently, Dr. Storer led the coating process development for the Metal Matrix Composites "Model Factory" Program at 3M. Presently, he is principal investigator for the 3M/DARPA Virtual Integrated Prototyping for Thin Films Program. This program is developing new sensors and mathematical models for the co-evaporation of complex oxide films and for the production of crystallographically textured functional coatings. Dr. Storer has broad experience in thin films for magnetic recording, wear resistance, and composites. In particular, he has been working the area of physical vapor deposition for 20 years. His special interests include cathodic arc plasma deposition and high rate electron beam technology.

Postdoctoral Fellow, Cornell University
Ph.D., Physics, State University of New York, Stonybrook
B.A., Physics, University of California, Berkeley